Upper Ocean Dynamics and Horizontal Variability in Low Winds

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Award Number: N00014-01-1-0029
http:www.whoi.edu/science/AOPE/dept/CBLAST/lowwind.html

LONG-TERM GOALS

Our long-term goal is to observe and understand the temporal and spatial variability of the upper ocean and to identify the processes that determine that variability. Air-sea interaction is of particular interest, but we will also investigate the coupling of the sub-thermocline ocean to the mixed layer. We seek to make observations over a wide range of environmental conditions with the intent of improving our understanding of upper ocean dynamics and of the physical processes that determine both the vertical and horizontal structure of the upper ocean.

OBJECTIVES

Little work has been done to explore air-sea interaction and upper ocean dynamics in very light winds, and few observations are available that describe the mesoscale and smaller scale horizontal variability of the upper ocean in such conditions. The objectives of this work are to observe and understand in low wind conditions: (1) how and why the vertical structure and properties of the surface boundary layer of the ocean (roughly the upper 20 to 50 m) evolve in time, and (2) how and why this evolution varies at horizontal lags of 10s of meters to 10s of kilometers on time scales of minutes to months. To do so we seek to observe and identify: (1) the processes that spatially modulate the vertical structure of the upper ocean (including the depth, salinity, temperature, and velocity of the mixed layer), (2) the processes at work at the base of the mixed layer (such as entrainment), and (3) the air-sea exchanges (fluxes of heat, freshwater, and momentum) that couple the boundary layers on horizontal scales of tens of meters up to 100 km.

APPROACH

We are working within a collaborative low-wind research effort, which is part of the Coupled Boundary Layers, Air-Sea Transfer program known as CBLAST-LOW and includes observational and modeling elements. The fieldwork will be done south shore of Martha's Vineyard. At that location, approximately 4 km south of the island in 19 m of water, an air-sea interaction tower will be installed to make detailed measurements of the fluxes, mean vertical profiles, and boundary layer vertical structure. The tower site is close to the Martha's Vineyard Coastal Observatory (MVCO), which will provide power, data communications, and supporting shore measurements; and winds there are predominantly light and from offshore (from the south to southwest) during the summer. Research aircraft will fly over the tower and out over the ocean, investigating the structure of the atmosphere out to 40 km upwind of the tower and using infrared to map sea surface temperatures (SSTs). Satellite

Report Documentation Page						Form Approved OMB No. 0704-0188
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1. REPORT DATE **30 SEP 2002**		2. REPORT TYPE				3. DATES COVERED **00-00-2002 to 00-00-2002**
4. TITLE AND SUBTITLE **Upper Ocean Dynamics and Horizontal Variability in Low Winds**						5a. CONTRACT NUMBER
						5b. GRANT NUMBER
						5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)						5d. PROJECT NUMBER
						5e. TASK NUMBER
						5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Woods Hole Oceanographic Institution,,Woods Hole,,MA, 02543**						8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)						10. SPONSOR/MONITOR'S ACRONYM(S)
						11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**						
13. SUPPLEMENTARY NOTES						
14. ABSTRACT **Our long-term goal is to observe and understand the temporal and spatial variability of the upper ocean and to identify the processes that determine that variability. Air-sea interaction is of particular interest, but we will also investigate the coupling of the sub-thermocline ocean to the mixed layer. We seek to make observations over a wide range of environmental conditions with the intent of improving our understanding of upper ocean dynamics and of the physical processes that determine both the vertical and horizontal structure of the upper ocean.**						
15. SUBJECT TERMS						
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON	
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**		

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

data on SST and surface roughness will be collected as well. Collaboration with modelers will use the observations and parameterizations based on them to examine and improve the performance of atmospheric and oceanic models; the models will also be used to guide the interpretation of the data.

In our component of CBLAST-LOW we will observe the vertical structure of temperature, T(z), of salinity, S(Z), of horizontal velocity, U(z), with vertical resolutions down to 0.1 m at a number of points separated by several m to 10's of km and will observe the surface forcing and how it varies horizontally. Temporal resolution will be at least 1 minute. To accomplish this several measurement platforms will be used. The first will be traditional surface moorings instrumented to observe surface forcing and the vertical structure of the ocean. Second, minimally intrusive, Lagrangian buoys supporting vertical arrays will be used to examine very near-surface vertical structure. The third will be horizontal arrays, using oil-booms to sample densely at small horizontal lags, supporting vertical sensor strings roughly every 10 m along a 100m surface array. The fourth will be a two-dimensional mesh to float on the surface and support vertical strings of instruments, thus allowing us to sample in 3-D.

Our experimental plan is to deploy the 3-D array close to the site of the tower, one surface mooring 40 km upwind from the tower, and another surface mooring 20 km upwind from the tower and then to use the 2-D arrays and drifting buoys to sample at various lags from the tower of between several hundred meters and 40 km. In this way we can observe the surface forcing and temporal evolution of the vertical structure of the upper ocean at several locations and contrast these observations with each other and with those at the tower; and, in addition, we can sample the horizontal variability on meter to 10s of km scales.

The timeline for the effort is as follows: in calendar 2000, acquisition of equipment and material; in calendar 2001, design and testing of the platforms and a pilot experiment south of Martha's Vineyard to test the arrays and refine the sampling strategies; in the summer of 2002, in conjunction with our work under our Secretary of the Navy Chair (N00014-99-1-0090) we carried out a study of the regional oceanographic and atmospheric variability in coastal waters south of Martha's Vineyard, which is the context for CBLAST-LOW; in the summer of 2003 we will participate in the main, collaborative experiment in July and August south of Martha's Vineyard; and after that to follow the field work with collaborative analyses and publication and presentation of results.

WORK COMPLETED

In late 2000 work was begun on acquiring instrumentation and designing the platforms. The greatest challenge was the 3-D array, so one focus of the work to date has been on designing, building, testing, and using the 3-D array in the pilot experiment in the summer of 2001. The 3-D array (Fig. 1) is made up of a net, 200 m by 200 m on a side with 20 m grid spacing. This net is made from foam-core fishing line and is deployed at the sea surface, held there under tension by anchors and surface flotation at each corner. The 3-D array was deployed in June 2001 without instrumentation from a fishing trawler, *FV Nobska*, to work out the logistics of deploying, unfolding, anchoring, and then recovering the array. At the same time, we deployed an array of 6 bottom-mounted temperature, salinity, pressure instruments spanning the southern shore of Martha's Vineyard and the planned domain of CBLAST-LOW. The later set of instruments was deployed to improve our knowledge of tidal flows on the south side of Martha's Vineyard both by observation and by supplying the ocean modelers in CBLAST-LOW with data they could work to replicate.

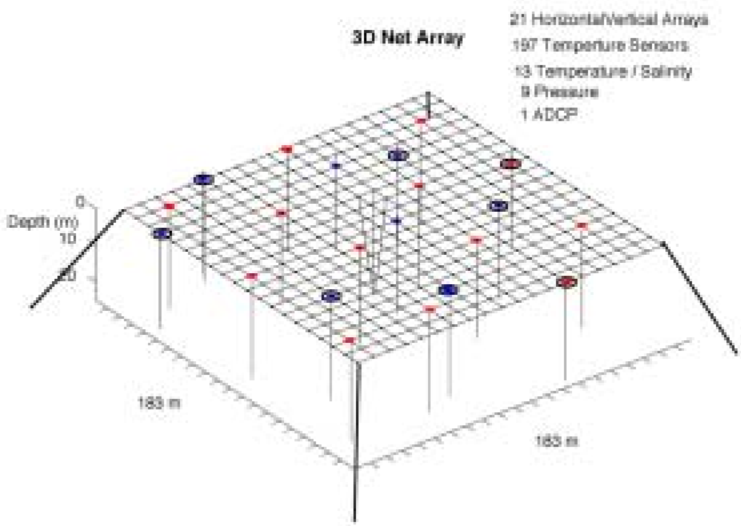

Figure 1. Drawing of the 3-D array, roughly 200 m on a side, with a 20 m grid on the surface and 21 vertical strings of instruments hanging down 25 m. Each of the corners is supported at the surface by a large float attached to anchors used both to moor and tension the surface grid.

In July 2001 we carried out a pilot experiment. Surface moorings were deployed at the 40 km and 20 km upwind sites and left in until mid-August, collecting a month of data; these obtained records of the surface forcing and temporal evolution of the vertical structure. For a week, we set and instrumented the 3-D array at the site to be used for the main experiment. Twenty vertical strings of instruments were attached to the 3-D array with instruments from the surface down to 25 m, and a Doppler profiler was hung from the center of the net. We also deployed a trial longline array 1 km in length perpendicular to the shoreline. After 3 days we recovered the longline array. After 5 days we recovered the 3-D array. While on site during that week, 135 CTD profiles were collected, including two sections from the tower site to 40 km offshore and one section parallel to the shore. The 6 bottom-mounted temperature, pressure, salinity instruments with recovered in mid-August with the surface moorings.

Apparent from the work in the summer of 2001 was the important role of synoptic weather systems and regional oceanographic variability (associated with mixing over shoals, intrusions of Gulf Stream and cool water masses, and other coastal processes) in setting the context and driving temporal and spatial evolution in the CBLAST-LOW region. To better understand this and to concurrently test the realism of regional atmospheric and ocean models in this setting (a goal of our Secretary of the Navy effort), we deployed an array of moorings at six sites (Fig. 2) from late June to early September 2002. Data return from these moorings was high; processing and analysis has just begun.

RESULTS

We established that it is possible to design, build and deploy a 3-D sampling array and for it to survive in the presence of tidal currents and a wide range of wind and wave conditions. The carefully designed anchor/tensioning system worked well and the array did not move through the duration of deployment. Sampling at high temporal resolution from a surface mooring near the net captured internal wave variability in the shallow, diurnal thermocline; and a DURIP proposal has been written to more completely equip the 3- D array with fast-response sensors for 2003. Analysis of the aircraft IR SST

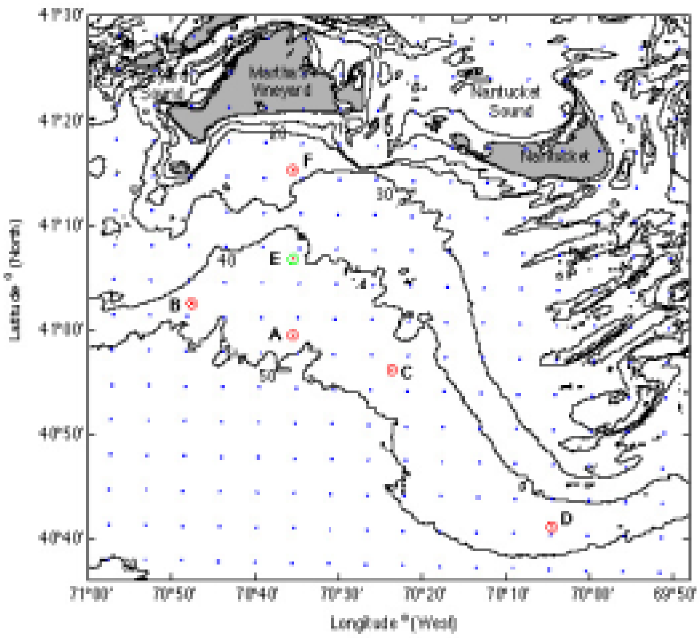

Figure 2. Map of the region south of Martha's Vineyard, Massachusetts, showing the six sites, labeled A through E, occupied by moorings to study regional atmospheric and oceanic variability and predictability in the summer of 2002.

data along with the moored data confirms links between SST and upper ocean variability. Deployment of fast response sensors on the 3-D array in 2003 would permit resolution of high frequency variability within the array and thus provide a unique data set linked to large eddy scale (LES) modeling and the observational studies at the air-sea interaction tower.

Longer scales of spatial variability were investigated in 2001 with mixed success. Four CTD transects, one running a long-shelf at the 25 m isobath and the other three made across-shelf from 9 m water depth (where the tower will be) out to a depth of 40 m some 35 km off shore, show the larger context, including the spatial scale structure of the mixed layer south of Martha's Vineyard and its change over the pilot experiment. In addition, an array of bottom mounted pressure transducers (tide gauges) was deployed. It was clear, however, that avoiding aliasing of the tides, collecting ocean data that could be used to improve the regional ocean models being refined as part of CBLAST-LOW, and assessing the contribution to spatial variability in the surface meteorology from synoptic weather systems as opposed to from local air-sea interaction were substantial challenges.

This motivated the combination of work under this project with the work under the Secretary of the Navy Chair study, Regional Variability and Predictability in the Upper Ocean, and the deployment in the summer of 2002 of the regional array shown in Figure 2. Each site had observations of surface forcing and, with good vertical resolution, of temperature, salinity, and velocity in the ocean. These moorings were recovered in early September. Data telemetered during the deployment shows that strong regional variability was found in both the atmosphere and the ocean. Analysis of this data has begun, as has interaction with the CBLAST-LOW oceanic and atmospheric modelers about their ability to replicate the observations.

IMPACT/APPLICATIONS

We believe that this work will provide some of the first direct observations within a volume in the upper ocean and thus some of the first assessments of horizontal variability of upper ocean structure on scales from meters up to several 10s of km and its relation surface forcing and oceanic processes. It will establish the representativeness of the studies to be done at the tower in CBLAST-LOW and be the basis for better understanding the sources of horizontal variability in the upper ocean in low winds. The work done in the summer of 2002 will provide a unique data set capturing atmospheric and oceanic variability in the coastal waters south of Martha's Vineyard and provide the means to assess the performance of present regional oceanic and atmospheric models in the coastal environment.

TRANSITIONS

The 3-D array technology and the knowledge of horizontal and regional variability gained will be made available. Data from such arrays can be used to motivate improvements to models (such as LES models) and to provide realistic structures for examining sound propagation in the upper ocean.

RELATED PROJECTS

This work is closely related to our studies of horizontal variability and predictability underway now with support from one of the Secretary of the Navy/Chief of Naval Operations Chairs. That work has focused on the impact of environmental variability on mine countermeasures activities in the shallow water. We have deployed instrumentation to collect data in exercises both in the Gulf of Mexico and off Camp Pendleton. Work in the final year of that effort has been directed at the CBLAST-LOW experiment area, both to benefit from ongoing CBLAST-LOW modeling efforts and to support CBLAST-LOW. CBLAST-LOW has benefited directly from the development of the light surface moorings, instrumentation, and data telemetry methods used in the fleet exercises. In return, CBLAST-LOW, with its explicit sampling of the horizontal as well as vertical and temporal dimensions, will be of great help in assessing how well a single surface mooring can provide adequate information about oceanographic and meteorological variability in a specific region.

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PUBLICATIONS

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